

## EDDY CURRENT DETECTION OF SUBSURFACE CRACKS IN ENGINE DISK BOLTHOLES

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### ABSTRACT

The development of a reliable eddy current inspection system to detect second layer cracks in sleeved engine disk bolt holes poses serious difficulties. This paper discusses some initial results obtained in two separate investigations that are aimed at advancing the state-of-the-art in eddy current detection of subsurface cracks. Both finite element design optimization results of a horseshoe shaped ferrite core probe, and the results of preliminary evaluation of the applicability of electric current perturbation (ECP) technique to the current problem are presented in this paper.

### INTRODUCTION

The development of a reliable eddy current inspection system to detect second layer cracks (0.03" x 0.015") in the sleeved (0.05" thick stainless steel) turbine disk boltholes poses serious difficulties.<sup>1</sup> Commercial eddy current units could not detect 0.06" x 0.03" EDM flaws (double the target size) behind 0.05" thick sleeve in a simulated bolthole specimen. It was found theoretically that the sleeve, because of higher electrical conductivity compared to that of the disk material, has significant affect on the sensitivity and transverse resolution of the sensor due to shielding

and current spreading. Partial and perhaps variable insulating layer between the sleeve and disk also affect the detection reliability.

Using a two-dimensional finite element numerical model, a theoretical sensitivity analysis was performed on various probe configurations of practical utility. From these studies, it was concluded that a horseshoe shaped ferrite core probe, due to its special magnetic characteristic (focussing concentrated field directly into the second layer), is capable of providing better sensitivity than other types. The design optimization results of this probe are presented.

The feasibility of detecting undersleeve cracks with electric current perturbation (ECP) technique was established through laboratory evaluation. Preliminary experiments with a simulated bolthole specimen show that with the ECP method, a flaw  $0.06'' \times 0.03''$  is easily detected through a  $0.05''$  stainless steel insert. However, a smaller flaw,  $0.03'' \times 0.015''$ , produced a much weaker indication. Possibilities for improving small flaw detectability are discussed.

#### FINITE ELEMENT DESIGN OF HORSESHOE CORE PROBE

The bolthole inspection geometry (Fig. 1) and the factors that complicate the development of a reliable eddy current system to detect the second layer cracks are well described in references 1 and 2. Initially, using a two-dimensional finite element numerical model, a theoretical sensitivity analysis was performed on an absolute eddy current coil (Fig. 2) with and without ferrite cup core (sensitivity  $\Delta|Z/z|$ , where  $\Delta z$  = change in impedance due to the presence of flaw,  $z$  = impedance with no flaw). The results suggested that such an eddy current system, in which the eddy currents flow in spiral path, would have to exhibit a sensitivity of  $10^{-5}$  for the reliable detection of subsurface cracks in the present geometry.<sup>1,2</sup> The sensitivity of commercial eddy current instruments is approximately  $10^{-3}$  or less. Based upon

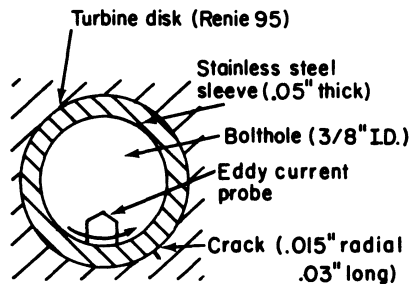


Fig. 1. Bolt hole inspection geometry.

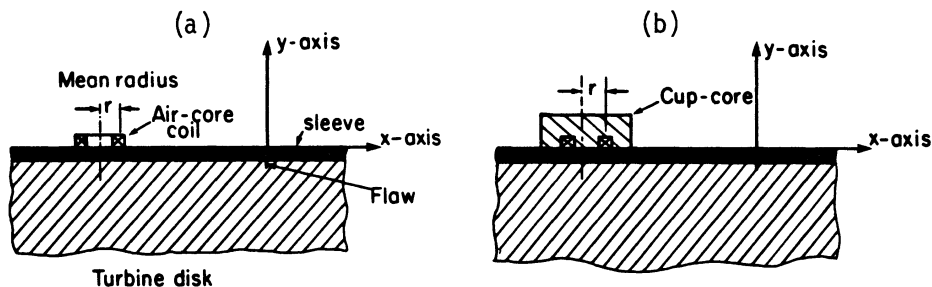


Fig. 2. a) Eddy current coil over a two-layer medium.  
b) Eddy current coil with ferrite cup-core over a two-layer medium.

these findings, it was concluded that it was highly improbable that state-of-the-art eddy current instrument would be found that was suitable for this inspection.

The coil sensitivity is a measure of the degree of interaction between the field and flaw in a test specimen. Both air-core and cup-core coils produce eddy currents that flow in a spiral path in the conductor under test. For a given surface flaw, higher probe sensitivities are possible with coils whose mean radii are comparable to the crack length. Such a generalized criterion is difficult to arrive at in the case of second layer crack detection, particularly when the thickness of the first layer is greater than the flaw size and the conductivity larger than that of the second layer. Therefore, one needs to use a probe that would focus a concentrated field directly into the second layer while minimizing spreading in the first layer. Theoretical results show that a U or horseshoe shaped ferrite core probe, possessing the desired special magnetic characteristic, is capable of providing better sensitivity than air-core and cup-core probes. The results of the initial analyses are presented here.

The two dimensional sketch of a U-core probe and the coordinate axes chosen for the finite element analysis are shown in Fig. 3a. Sensitivity values were predicted at different probe locations on the x axis as the probe moves past the defect.<sup>3</sup> The predicted U-core probe signals are plotted in Fig. 3b for two different flaw sizes and for  $L = 0.0842$ ". U-core probes produce single peak signals with better transverse resolution compared to double peak signals produced by circularly wound air-core and



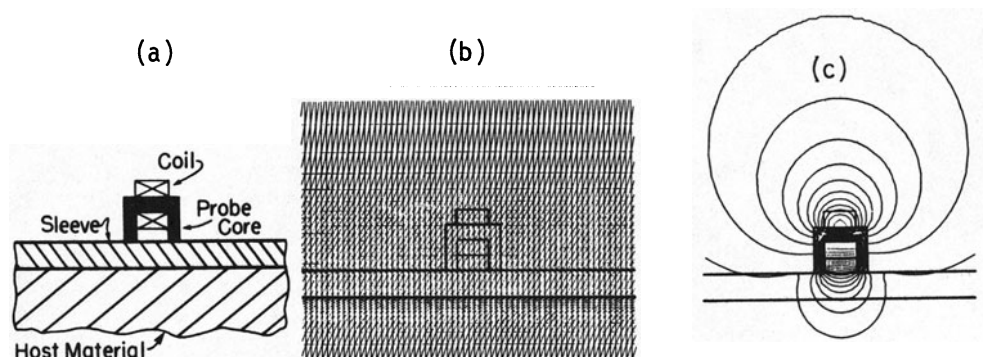


Fig. 4. a) Two dimensional geometry for the numerical analysis.  
 b) Part of finite element discretization.  
 c) Flux plot (frequency: 40 kHz)

maximum sensitivity occurs when the probe comes directly above the flaw (i.e., for the probe position shown in Fig. 3a).

In the two dimensional analyses discussed so far it was implicitly assumed that a) both the flaw and coil had infinite extent perpendicular to the plane of the diagrams (Figs. 2 and 3a), and b) the bolt hole diameter is infinite (i.e., the curvature effect was neglected). Within the limits of the two dimensional analysis (assumption a) the effect of bolthole curvature on the probe sensitivity can be studied by considering a circular geometry instead of a flat two layer medium shown in Fig. 3a. Thus, the approximation of a sleeved bolthole geometry as a flat two dimensional media can be eliminated altogether. It was predicted that the maximum signal amplitude coming from the circular geometry is 15.2% more than that coming from a flat two dimensional geometry.<sup>2</sup>

#### ELECTRIC CURRENT PERTURBATION METHOD

The field/flaw interaction in the bolthole inspection geometry is three dimensional in nature. In the absence of a viable three dimensional modeling technique, a two dimensional numerical model was employed to study the current flow around the crack.<sup>1</sup> This study suggested that a technique, called the electric current

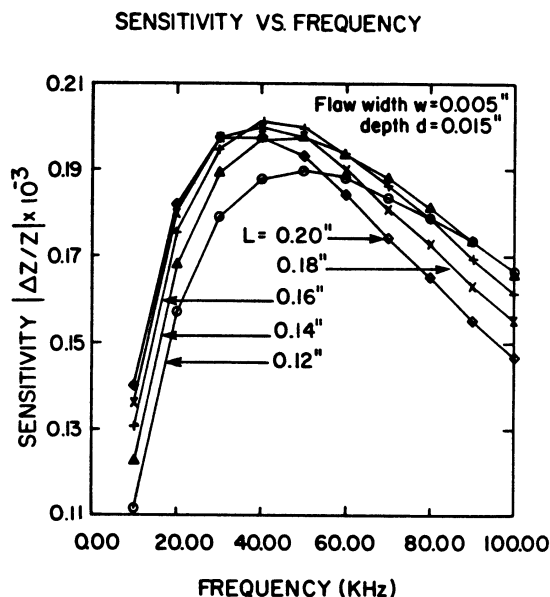


Fig. 5. Sensitivity vs frequency for different pole gaps ( $L$  in Fig. 3a).

perturbation (ECP) technique would be an appropriate candidate to evaluate for this problem.<sup>4</sup> This technique consists of establishing an electric current flow in the test specimen and then detecting localized perturbations of this current flow about a crack. This current perturbation is measured by using a small noncontacting probe to detect the associated magnetic flux perturbation as a function of position at the surface of the specimen.

The feasibility of detecting under sleeve cracks with the ECP method was established through laboratory experiments. The drawing of a sleeved bolthole sample prepared for this experiment is given in Fig. 6a. Two boltholes were prepared and then sleeved with two flaw sizes included. One of these is the target flaw, .030" x .015", and the other flaw was chosen to be twice these dimensions. Figure 6b shows the ECP scans of these two EDM flaws at 50 kHz. The large signal excursion on the right side of the traces is due to a seam in the insert (not visible on the exterior of the stainless steel tubing used to fabricate the sleeve). The rather appreciable base line drift seen in these charts is probably due to lift-off variations as the probe moves circumferentially around the inside of the hole. In Fig. 6b, the larger EDM slot (0.06" x 0.03") is clearly and cleanly discernible above the noise. However, the trace corresponding to the target flaw does not show

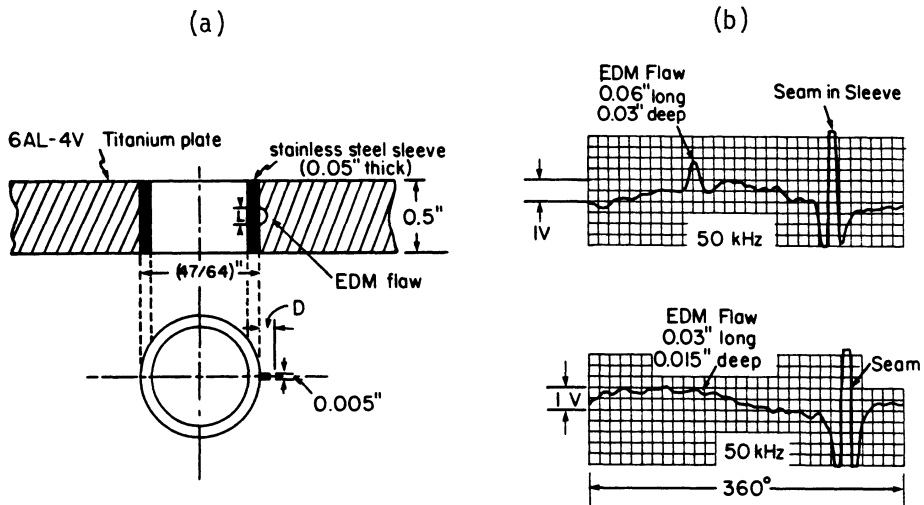


Fig. 6. a) Bolt hole specimen used in electric current perturbation (ECP) experiment.  
b) ECP scan of sleeved bolt holes. (EDM slots in the outer material).

a clear result. It would be expected on the basis of the larger flaw that the signal for this flaw would be approximately the same magnitude as the noise (which it apparently is) and therefore undiscernible with the present set-up.

It is regarded that the evaluation of the ECP method is highly promising for this application. The fact that the target flaw produced an undiscernible signal separated from the noise is not at all surprising inasmuch as the current probe and the associated electronics were designed for surface flaws. Improvements in signal/noise ratios can be expected through improvement of probe design for the subsurface problem and in signal detection techniques. The recent ECP model calculations aimed at optimizing the differential sensor parameters for detecting the second layer cracks have shown a three-fold improvement in signal/noise ratio (Fig. 7). The traces in Fig. 6b were obtained using the laboratory model ECP system (meant for surface inspection) in which the coil spacing  $D$  was only 0.27mm (i.e., corresponding to the left end of the curves in Fig. 7). The data presented in Fig. 7 indicate clearly that an increase in coil spacing from 0.27mm to about 1.2mm would improve the signal/noise ratio by a factor of three, which would suffice to make the target flaw easily detectable.

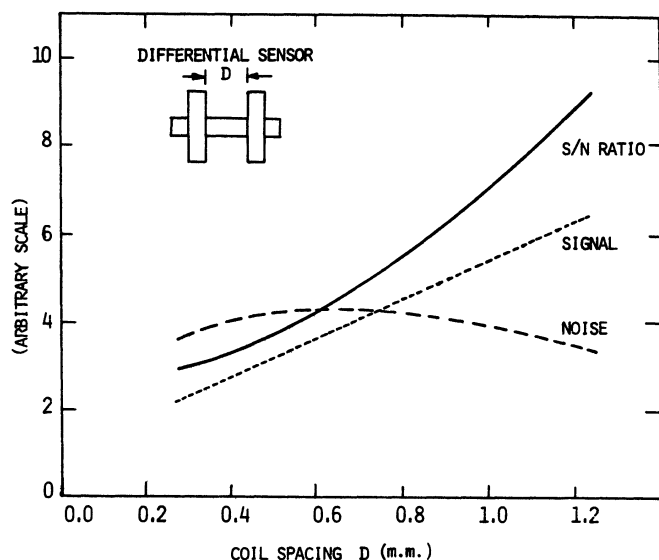


Fig. 7. Results of sensor optimization study for under sleeve crack detection using ECP technique.

## CONCLUSION

From the results of the analyses it was concluded that an optimized (probe dimension and excitation frequency) U-core probe is better suited for inspecting second layer cracks compared to air-core and cup-core probes. It is recognized that the two dimensional modeling techniques do not accurately represent the entire problem of interest and that the results must be interpreted with some caution. In a separate investigation it was shown that the 2-D calculations over estimate the sensitivity by a factor of 10 for the practical problem at hand.<sup>5</sup> Therefore, the theoretical results suggest that a sensitivity of  $|\Delta z/z| \approx 10^{-5}$  would be required in the instrumentation for the reliable detection of subsurface cracks in the present geometry.

The preliminary results of the ECP experiments (using surface probe), and signal/noise ratio prediction for subsurface probes are highly promising for this application. Additional work that is required to quantify the potential of state-of-art ECP probes includes estimating the magnetic flux leakage at the position of the sensor due to current deflections around the flaw and assessing the effects upon detection reliability of a partial and perhaps variable insulating layer between the sleeve and disc. Efforts



are underway towards developing these two improved eddy current systems that would provide the required sensitivity for the sleeved bolthole inspection.

#### ACKNOWLEDGEMENT

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#### DISCUSSION

From the Floor: It seems like you're modeling one type of probe and you're experimentally using another type. Can you tell me why?

R. Palanisamy: We don't have the eddy current system built up, but we are working on it right now, so taking the houseshoe-shaped probe, we have gone through the experimental and theoretical analysis just to see if it is feasible. That is one area. We are trying the ECP method, electric current perturbation, also the pulse radiating current technique. So it's about three methods; there's no connection between them.